Mobility of Military Vehicles at TARDEC

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May 15, 2012

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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-History and Background -Modeling and Simulation at TARDEC -Current Research Efforts -Future Growth and Trends

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Agenda

- History and Background
- Modeling and Simulation at TARDEC
- Current Research Efforts
- Future Growth and Trends

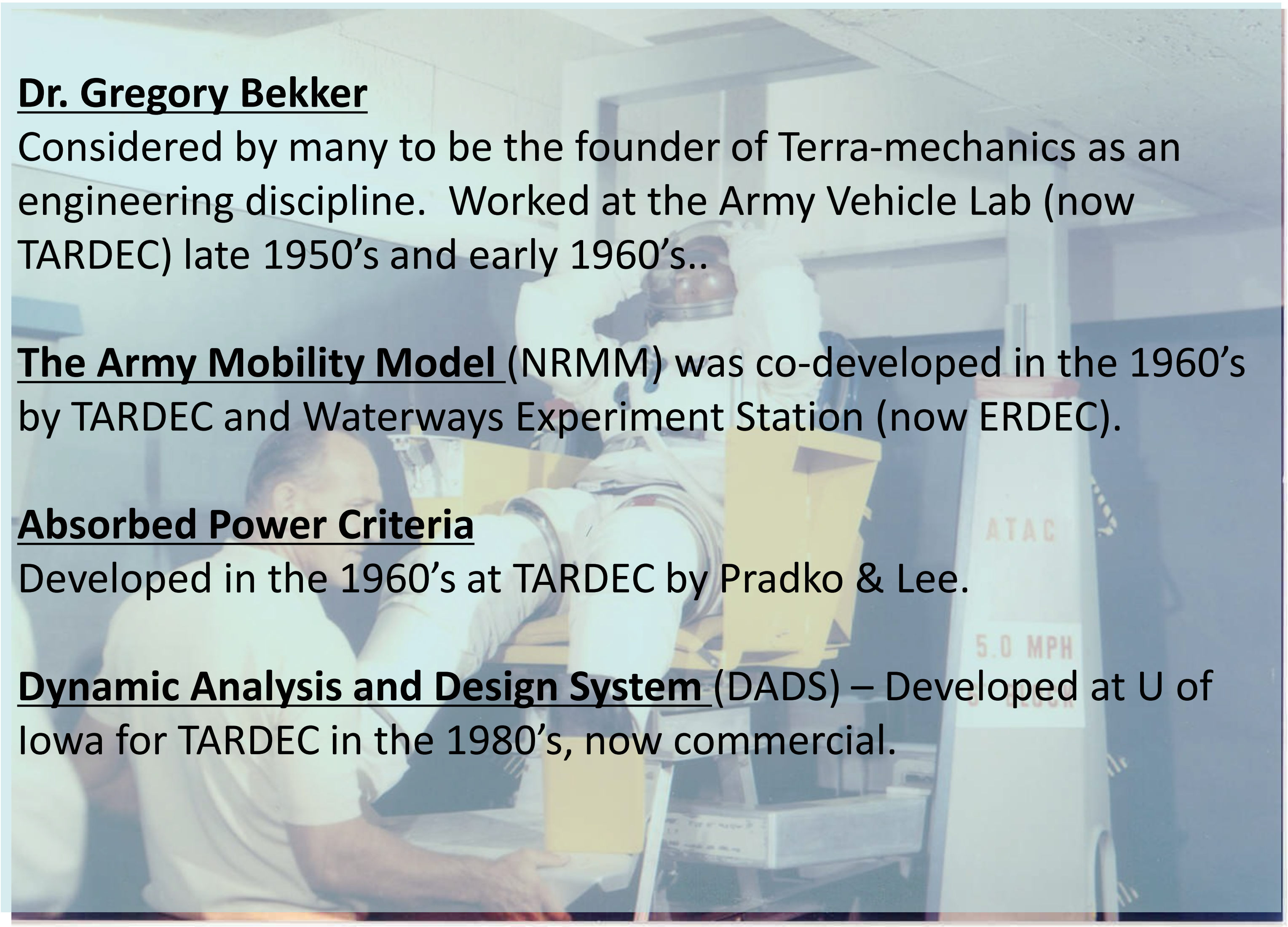
Historical

<u>Dr. Gregory Bekker</u>
Considered by many to be the founder of Terra-mechanics as an engineering discipline. Worked at the Army Vehicle Lab (now TARDEC) late 1950's and early 1960's..

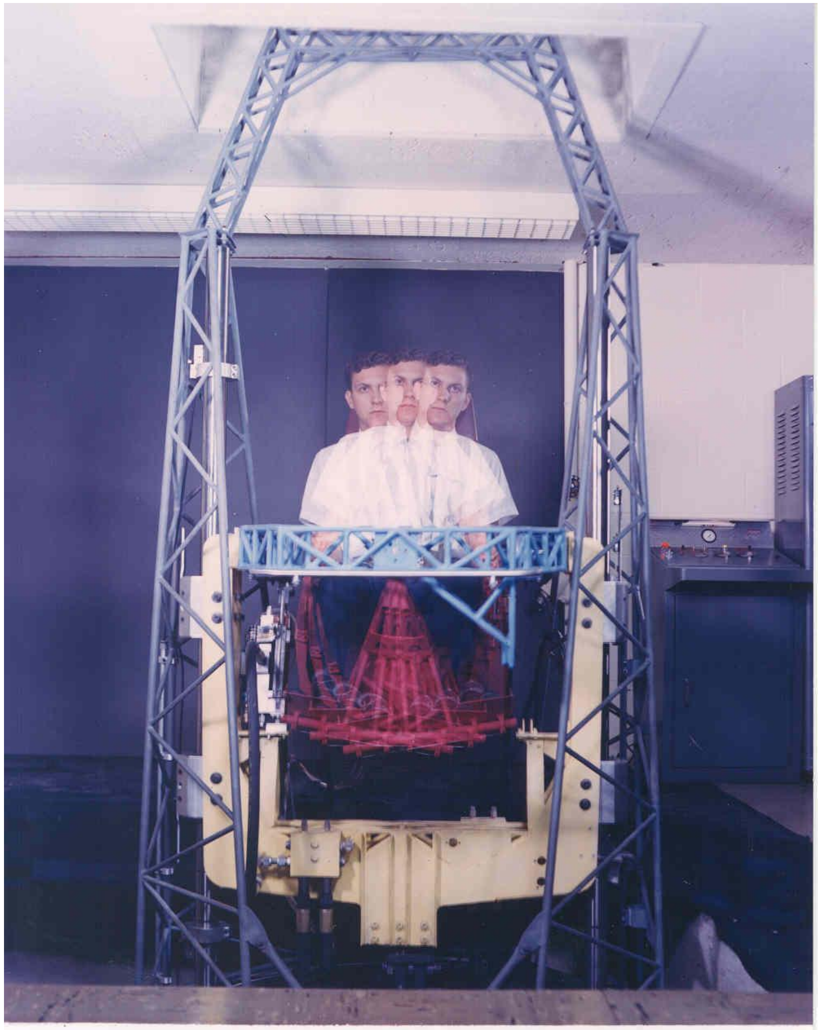
<u>The Army Mobility Model</u> (NRMM) was co-developed in the 1960's by TARDEC and Waterways Experiment Station (now ERDEC).

<u>Absorbed Power Criteria</u>
Developed in the 1960's at TARDEC by Pradko & Lee.

<u>Dynamic Analysis and Design System</u> (DADS) – Developed at U of Iowa for TARDEC in the 1980's, now commercial.



Ride and Shock Quality Research 1962-1972



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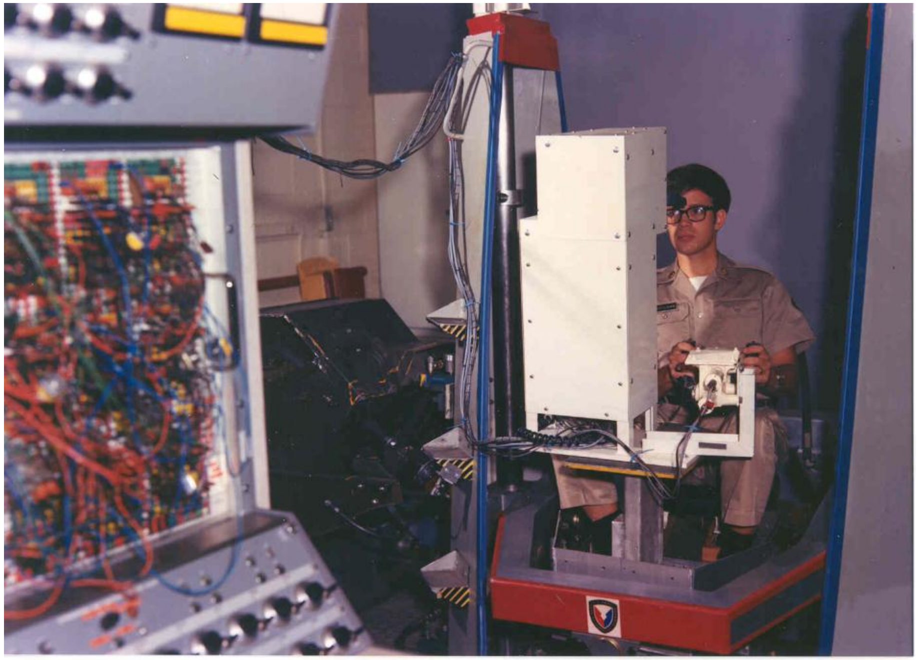
Dynamic Simulations Laboratory Drivers Seat Action Test.



Analog Computer Used to Compute Absorbed Power to Quantify Ride Quality

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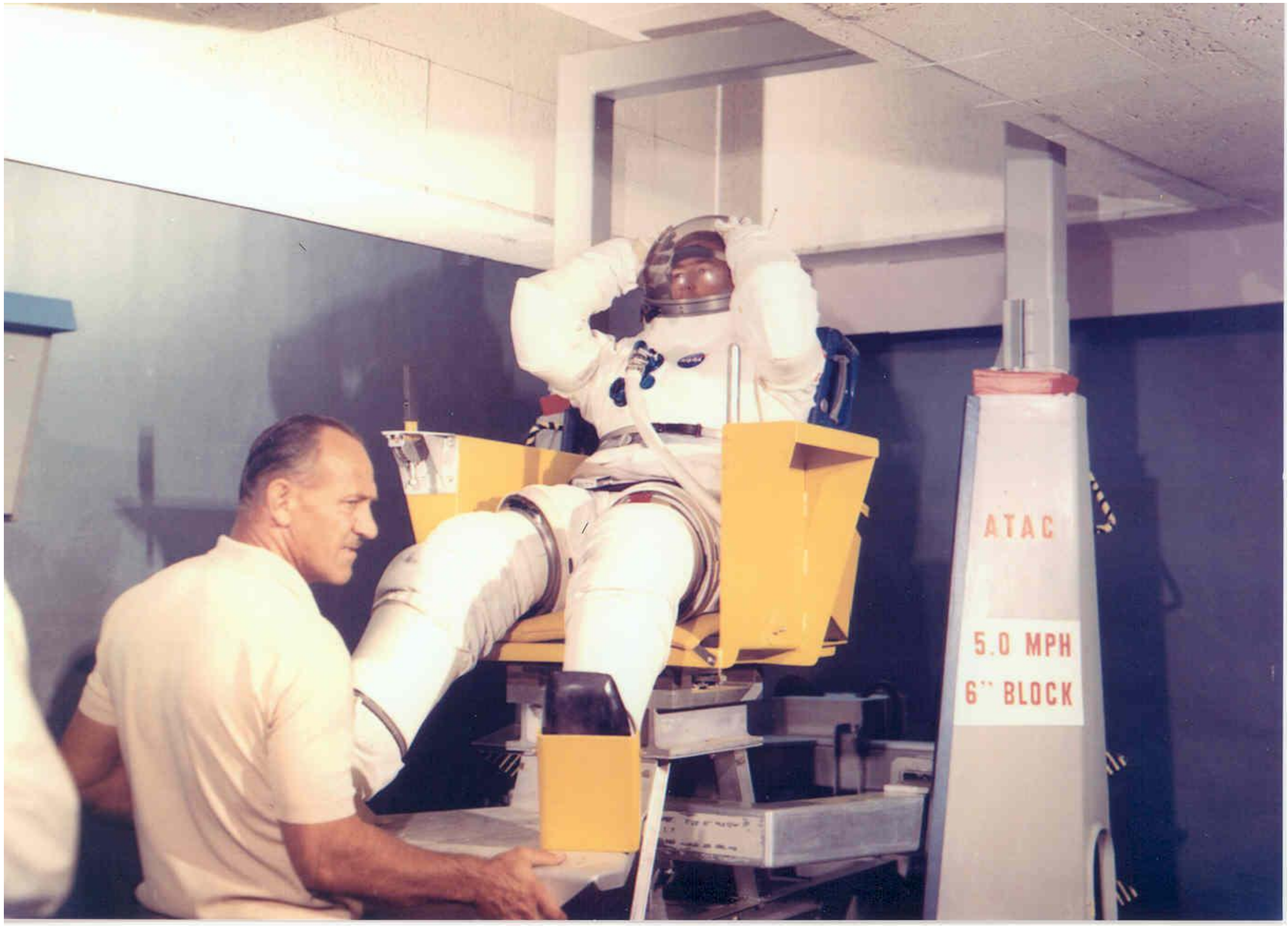
Astronaut Lunar Rover Training
Date Unknown



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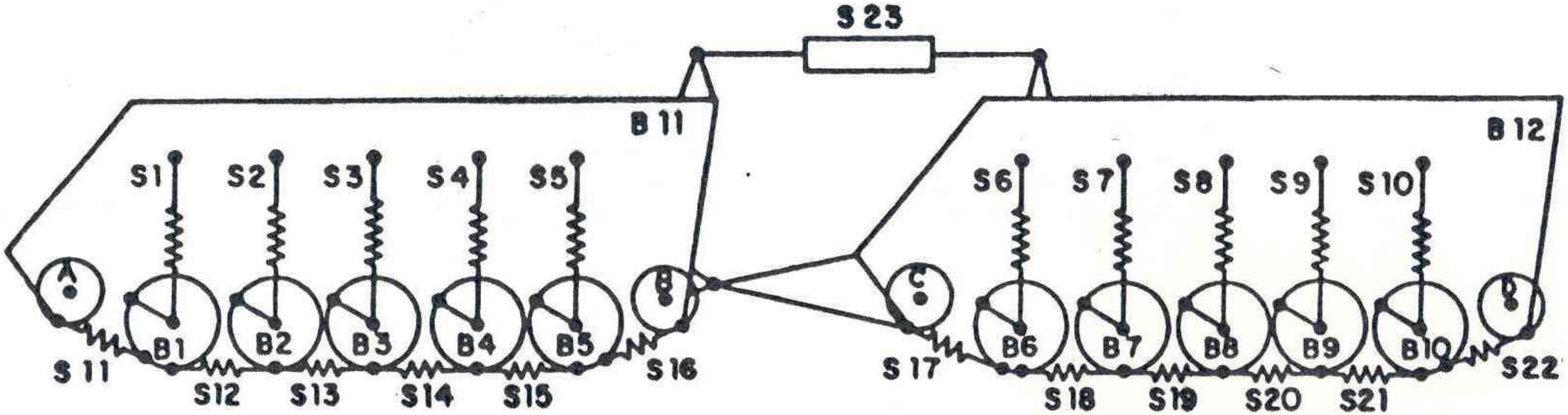
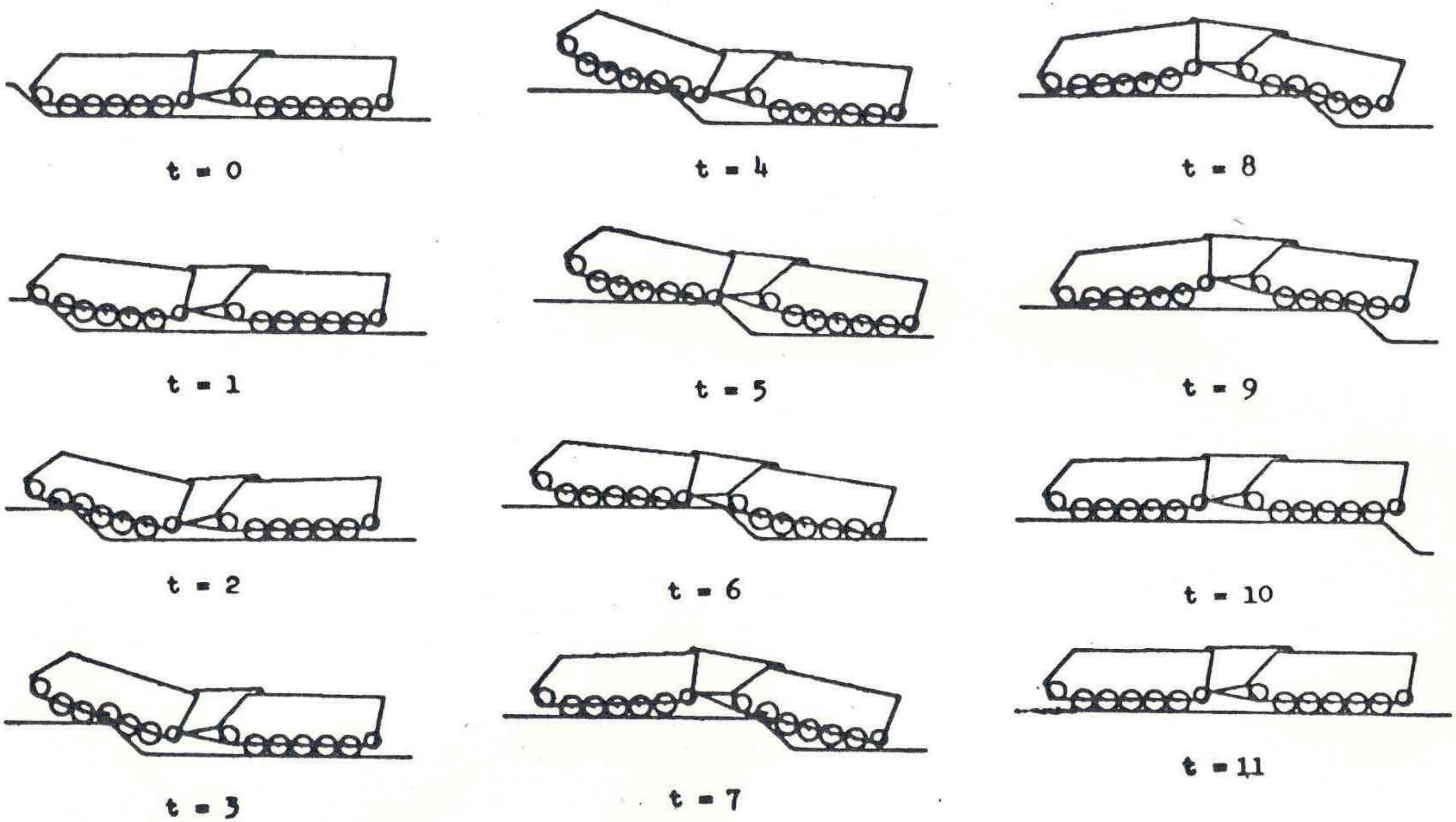
Pre-DADS Formulation of Coupled M113s 1977



A computer model of the coupled M113's.

Pre-DADS Animations of Coupled M113s 1977



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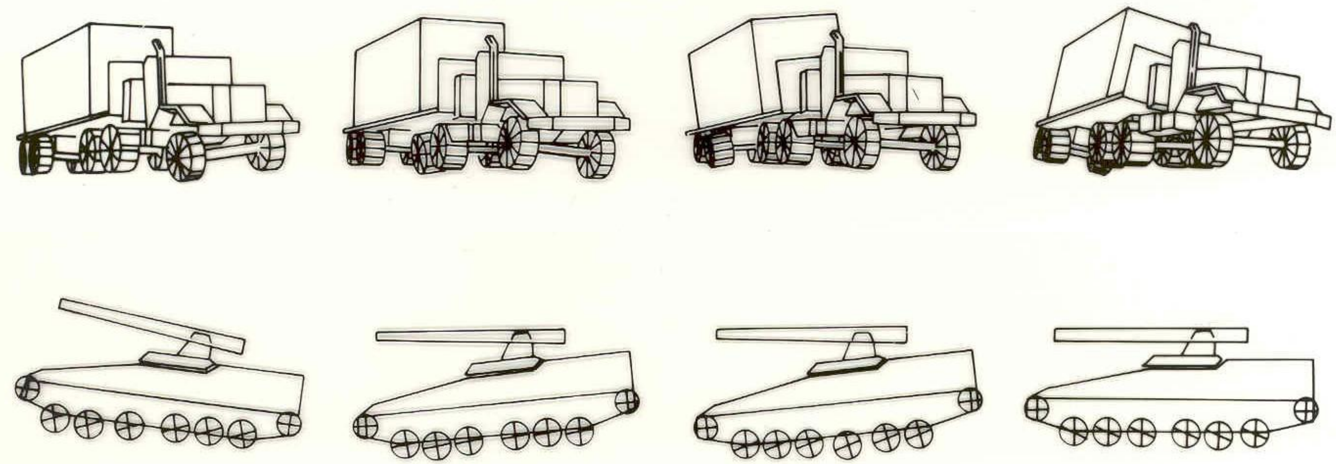
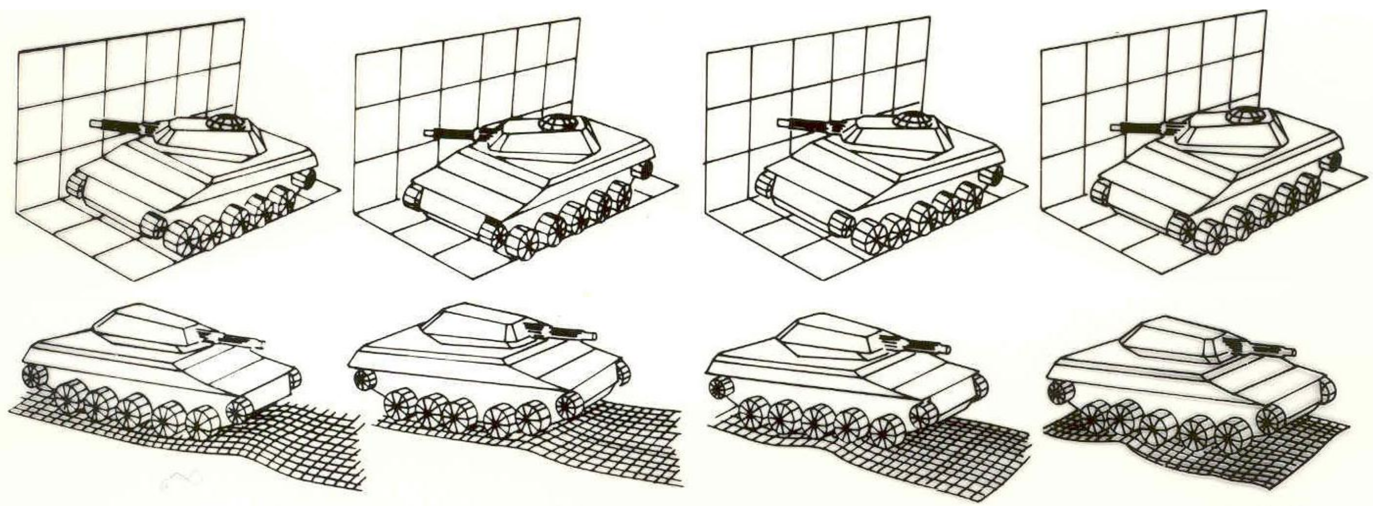
Pre-DADS Simulations

1980

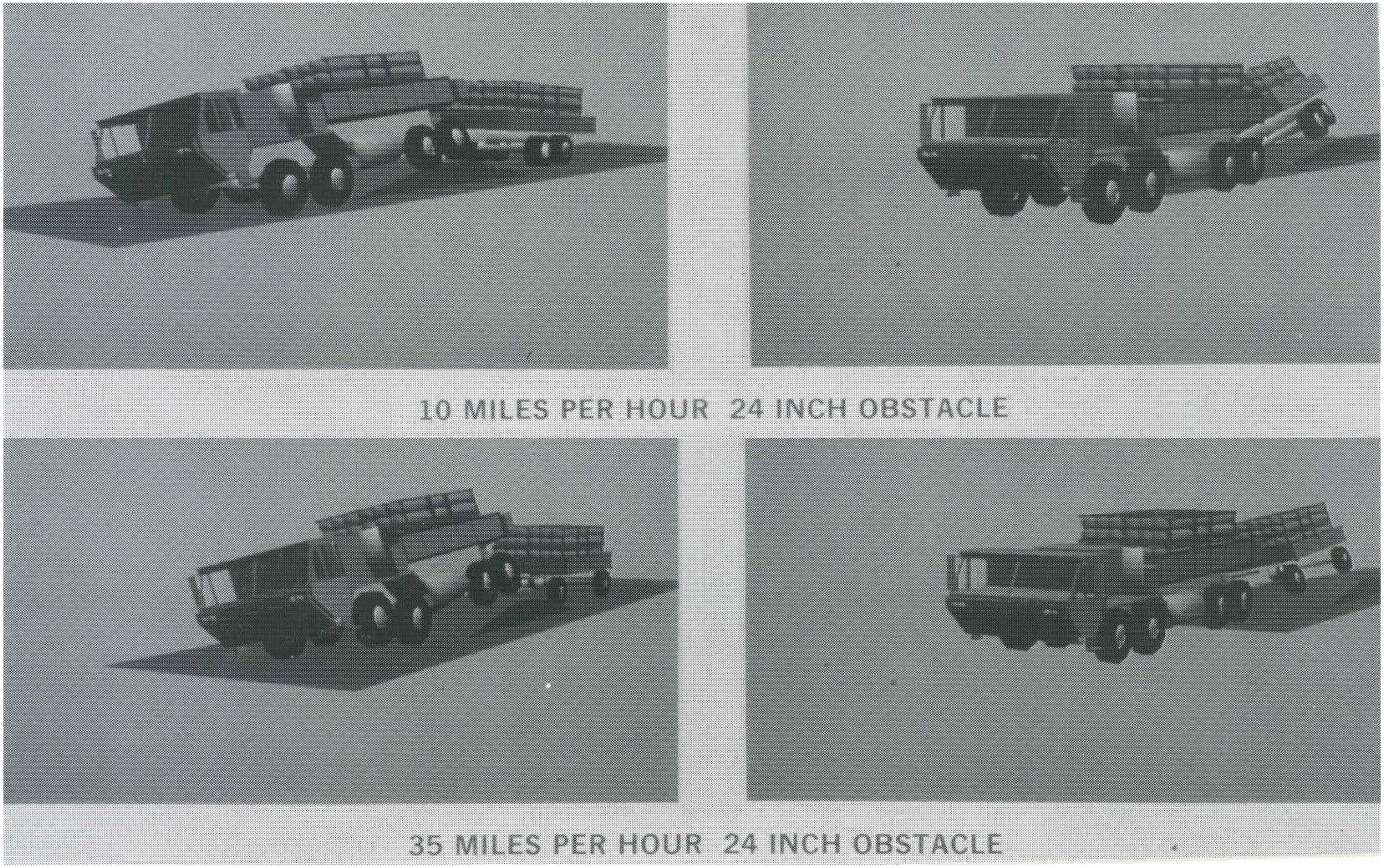
1981



1982



HEMTT-HEMAT
Ca. 1985



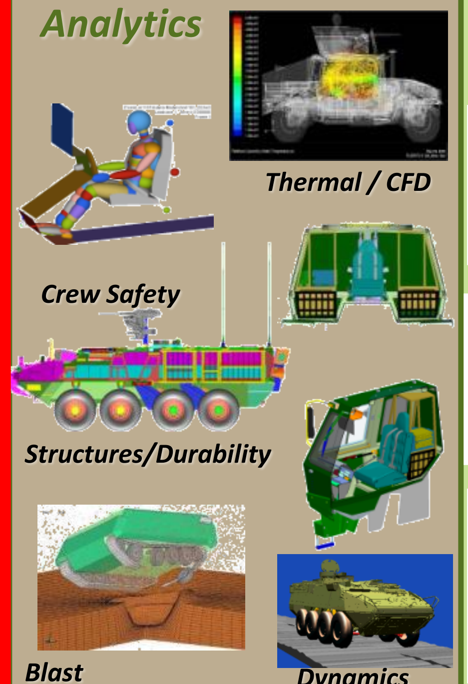
Concepts / Analysis / System Simulation / Integration (CASSI)

System-centric, M&S-based Services to integrate and assess the impacts of new concepts/technologies and upgrades to existing systems.

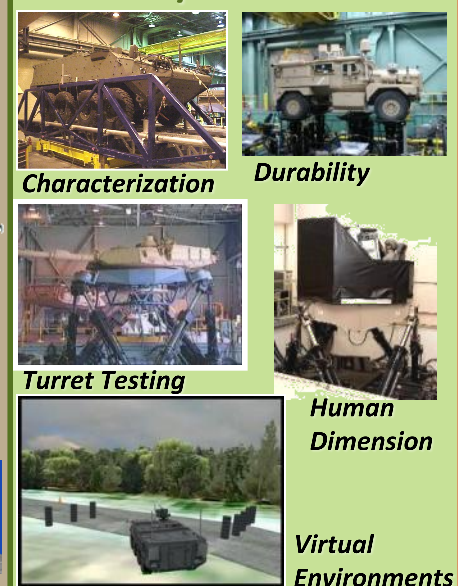
C A SS I

Concepts

Analytics

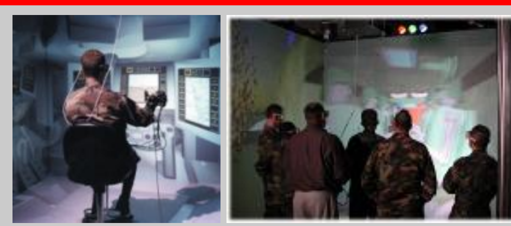


Hardware & Man-In-The-Loop Simulation



Integration & Demonstrators

HPC & Data Management



CAVE – Virtual Design Reviews

Key Partnerships with TARDEC Technology Groups, other Army RDECs/Labs, PM's, TRADOC – MCOE, TACOM Sys & Cost Analysis, ATEC

Acquisition and Life Cycle M&S Support (CASSI "A" Analytics-*Dynamics and Structures*)

- **Vehicle Dynamics**
  - Ride and Shock Quality
  - Lateral Stability
  - Handling (oversteer / understeer)
  - Braking
  - Rollover
  - Soft-soil Mobility
  - Suspension/vehicle Loads
- **Structural Analysis**
  - Reliability Modeling and Analysis
  - Failure analysis
  - Durability degradation
- **Technology Insertion**
  - Semi active/Active suspensions
  - Weight growth issues
  - Others (suspension upgrades, etc)
- **Research and Development**
  - Operational uncertainties and Reliability
  - Accelerated Testing
  - Rollover
  - Track, Tire and Terrain Modeling etc.

CASSI "SS" – System Simulation

Ground Vehicle Simulation Laboratory

- Vehicle Characterization
- System Durability Studies
- Performance Validation
- System "Shakedown" Testing
- Man-In-the-Loop Testing

TARDEC's Suspension Characterization Machine

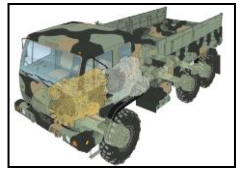
✓Suspension vertical stiffness
✓Toe vs. vertical travel
✓Camber vs. vertical travel
✓Roll Center Height
✓Overall Steering Ratio
✓Wheel X,Y,Z motion wrt. travel

Machine Specs:
Vehicle Weight Capacity: up to 100,000 lbs
Suspension Travel: Up to 24 in (total)
Maximum Compressive Force: 60,000 lbs per axle.
Track width: up to 110 in.
Vehicle width up to 150 inches.
Wheel base up to 325 inches.
Vehicle length up to 600 inches.

Coming in May!

Major Programs Supported

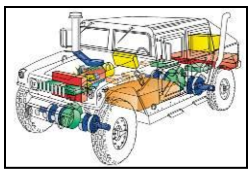
HMMWV FoV



FMTV FoV – Armor Effects on Performance

JLTV - SSEB, AoA, TD Phase Performance Assessments

GCV – Concept Analysis, Power Pack Sizing, Req't Definition, CDD Support



XM1124 HE HMMWV - Hybrid Electric Vehicle Evaluation and Assessment

HEMTT – Armor Effects on Performance

M915/NGLH – Armor Effects on Performance

Abrams – AGT 1500 Testing, AoA

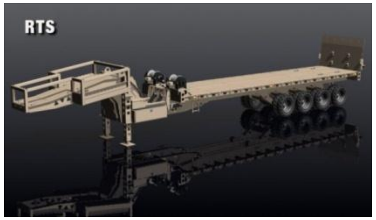
MRAPs – SSEB, Tech Insertion, Armor/Power Effects on Performance

Bradley – AoA, Upgrade Assessment

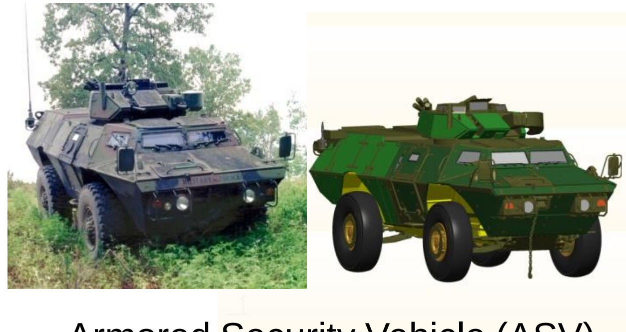
Stryker – Belly Armor/Power Effects on Performance

Paladin – PIM Analysis

Major Programs Supported (Cont'd)



Joint Recovery and Distribution System (JRaDS) Joint Capability Technology Demonstration (JCTD) Program

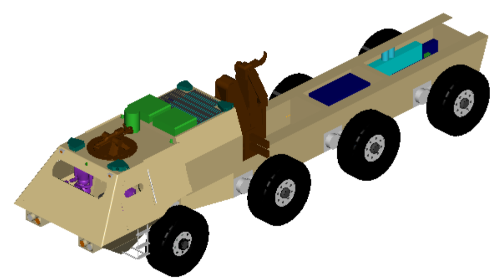


Armored Security Vehicle (ASV)

MRAP All Terrain Vehicle (M-ATV)

Expanded Capacity Vehicle (ECV)

Joint Explosive Ordnance Disposal Rapid Response Vehicle (JERRV)



Future Tactical Truck System (FTTS)

Mobility Requirements in Military Vehicles

Conventionally, tied to operational performance:

- Ride Quality: 6W Absorbed Power, Half-round Bumps
- NATO Lane Change
- Turning Radius
- Lateral Acceleration Capability in a Steady State Turn
- Soft Soil Mobility, Vehicle Cone Index
- Tilt Table

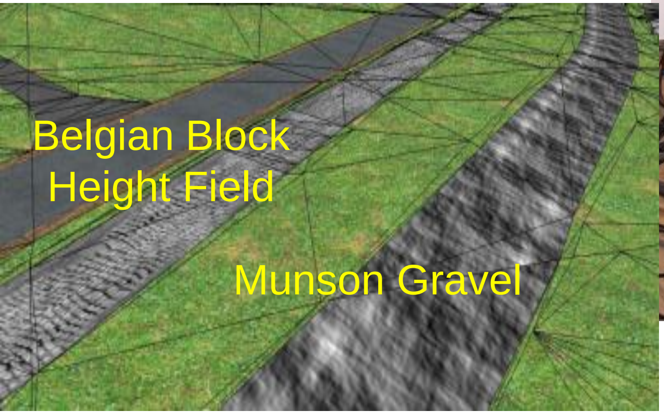
Open Research Ideas:

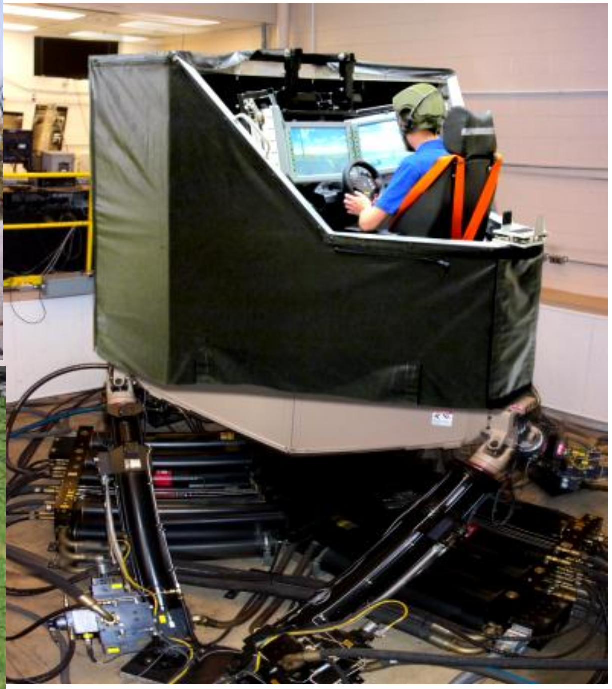
- Requirements based on operational uncertainties
- Off-road rollover
- ESC performance under on-road and off-road conditions
- New soft-soil mobility metrics
- Steering feel for fatigue, driving confidence

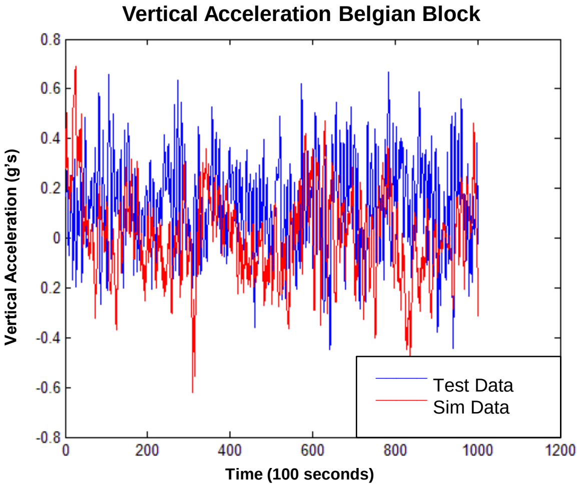
Current Research Effort Examples

- Investigating state of the art active suspension technologies (such as MR damper) using **driving simulators**
- Developing active/semi-active suspension for off-road **rollover mitigation and ride quality.**
- Considering probabilistic approach for operational uncertainties, reliability, and lifecycle cost.
- Developing accelerated testing techniques to improve reliability and mobility.
- Utilizing multi-disciplinary approach to maximize survivability while meeting land mobility requirements (and water mobility for amphibious).
- Terrain, track, and tire modeling, etc.
- …

Examine the effectiveness of MR dampers against passive dampers on a Stryker Vehicle

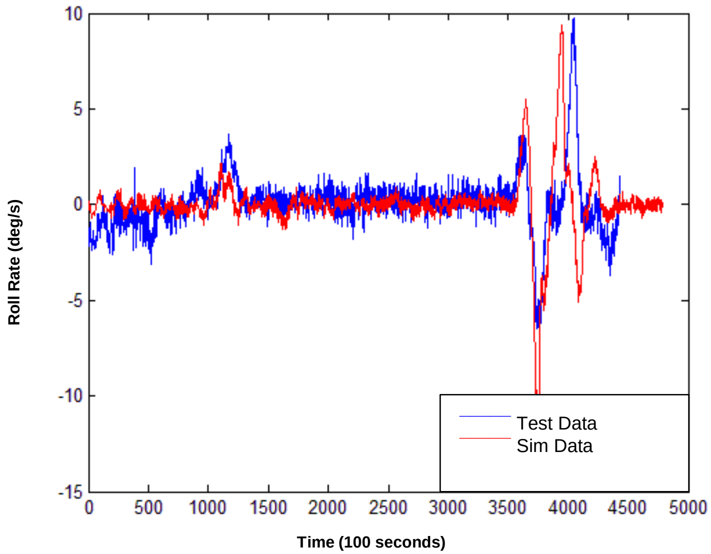


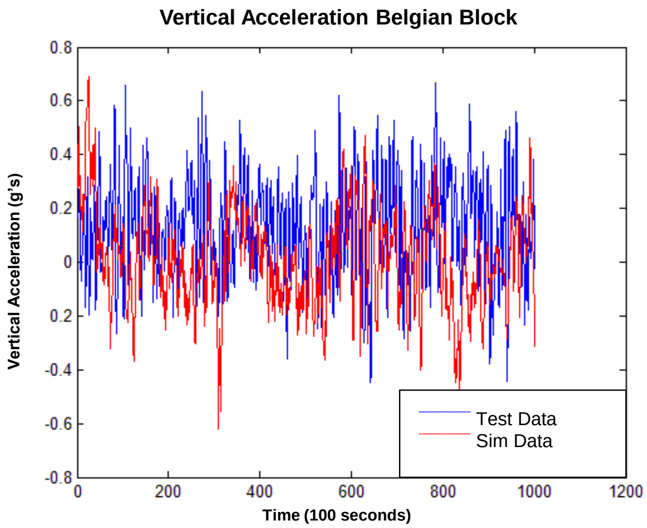




Model Validation

- Driver in the loop
- Max lateral acceleration on skidpad
  - 0.4G max lateral acceleration at 40 mph
- NATO lane change
  - Roll Rate
- Ride on simulated Belgian Block course
  - Vertical Acceleration





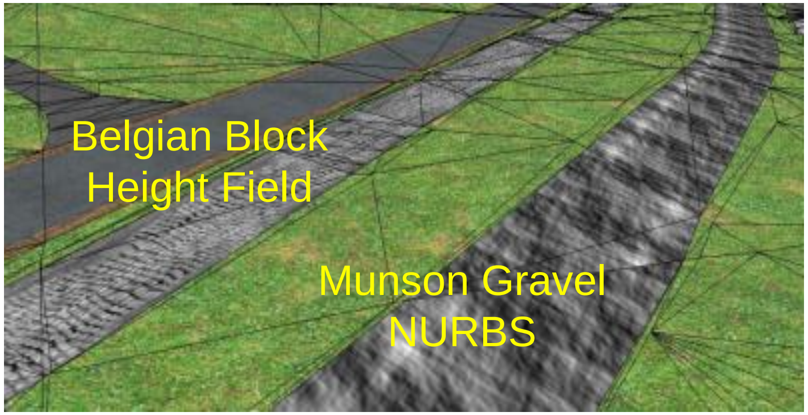
NURBS & Height Field Modeling

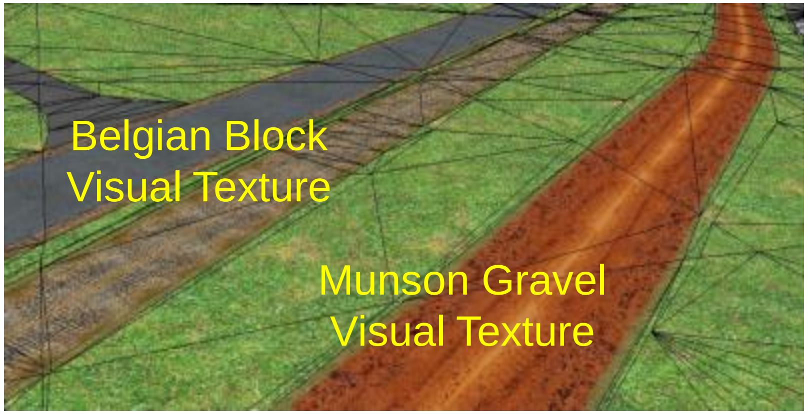
Challenges

Suspension performance requires enough resolution to capture suspension modes

Very dense terrain degrades real-time performance

- NURBS
  - Used the Munson Gravel courses based on RMS values of Munson Gravel.
- Height Field
  - Uses texture and RMS of Belgian Block created from photographs of Belgian Block Course
  - Driven and reworked to produce representative response based on test data.





Ride Demonstration Results

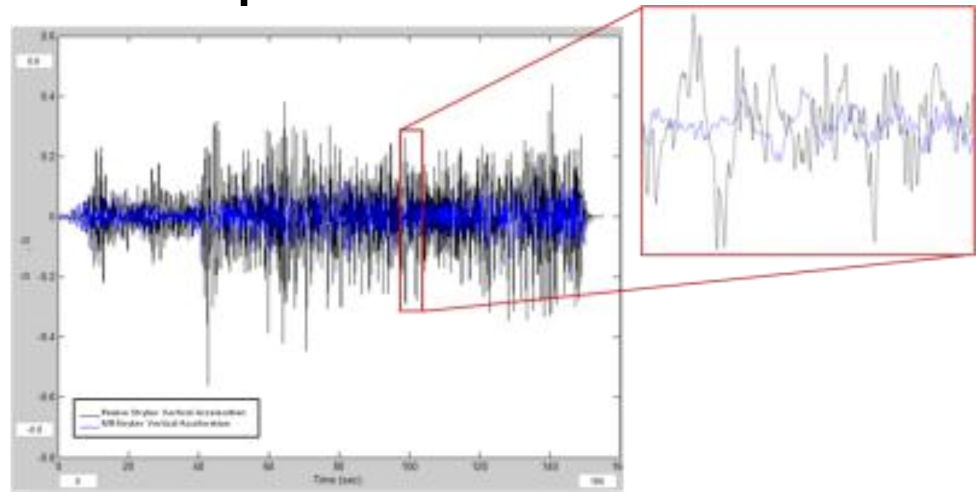
Demonstrated Benefits:

✓Lower Vertical Acceleration

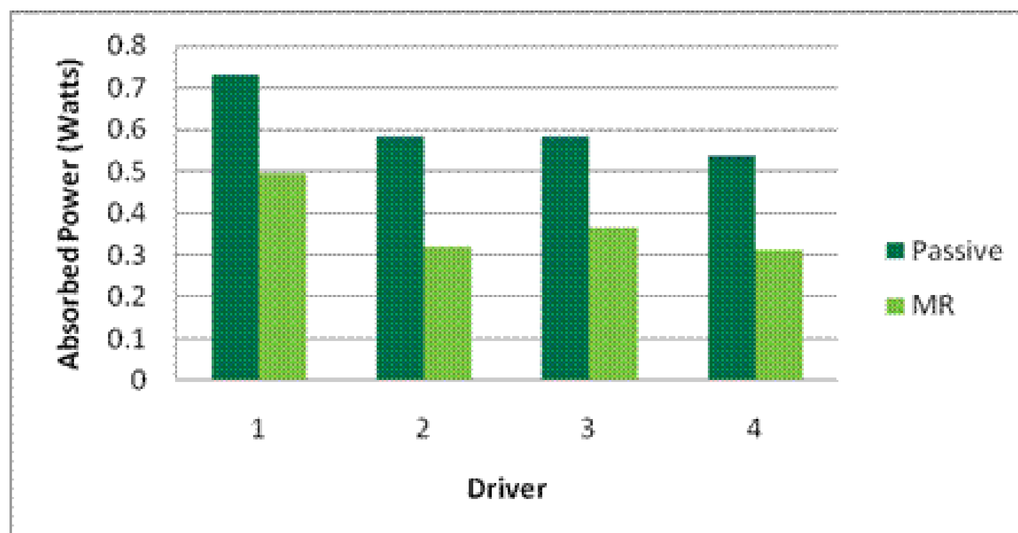
✓Reduced absorbed power

✓Improved subjective experience

Sample Vertical Acceleration



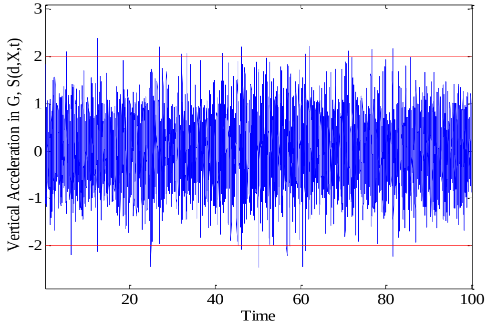
Sample Absorbed Power

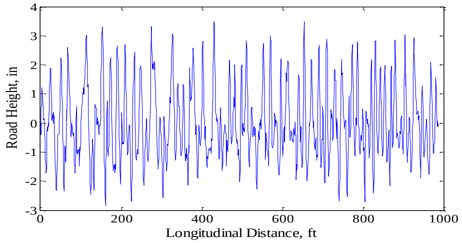


Operational Uncertainties (Ride Example)

Random Variables

Vertical Accel. (G)





Terrain

Stochastic Input → Stochastic Output

Requires Probabilistic Approach

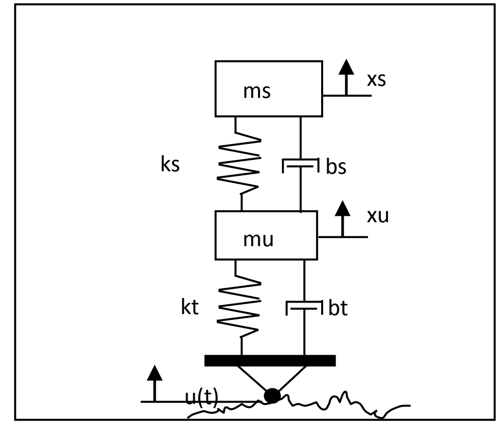
Quarter-Car Model on Stochastic Terrain

Constant design parameters:

ms =1000 kg

mu =100 kg

Vehicle speed = 20 mph



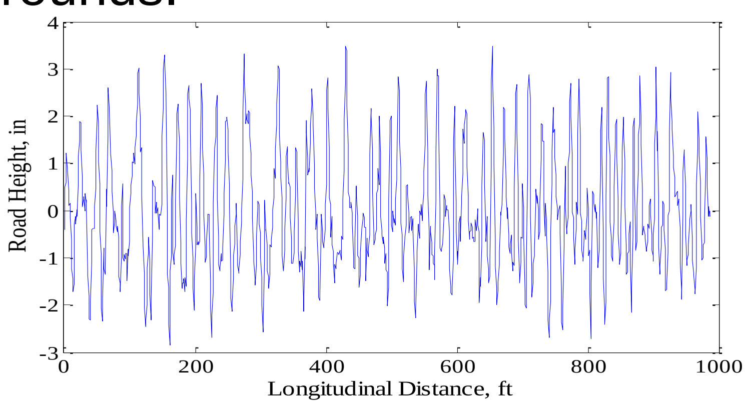
Random Output Process
(Vertical Acceleration, G')

Random Input variables

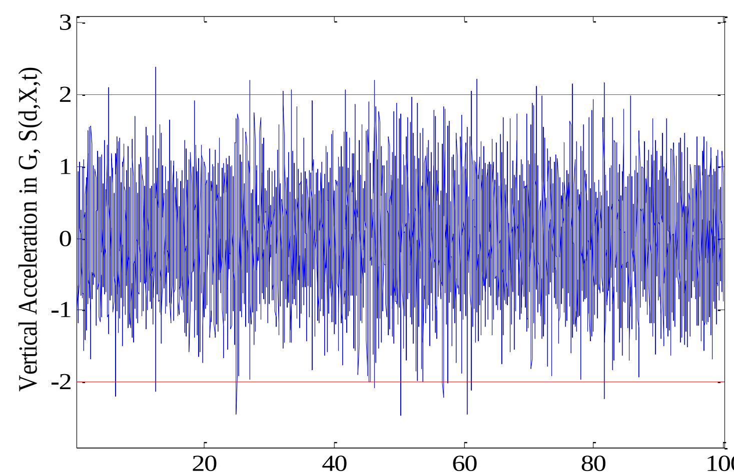
Damping, $b_s \sim N(7000, 1400^2)$

Stiffness, $k_s \sim N(40\times 10^3, (4\times 10^3)^2)$

Random Input Process: Experimental Stochastic Terrain from Yuma Proving Grounds.

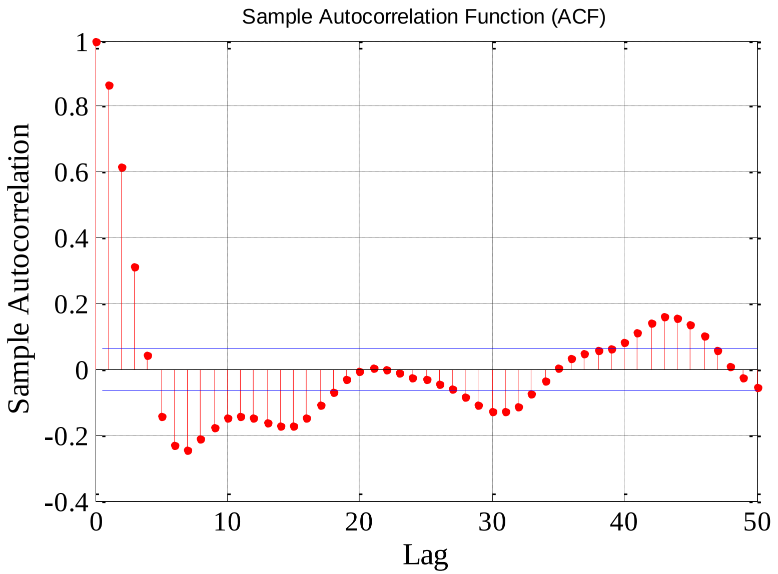


Threshold = 2G

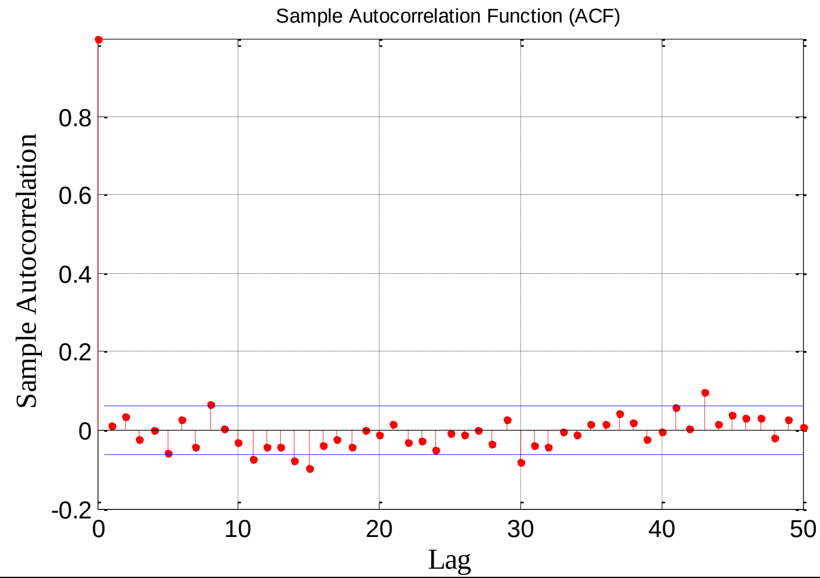


AR(3) model was identified based on:

Autocorrelation Function



Autocorrelation of Residual process

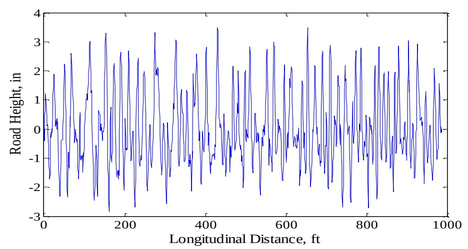


$$u_i = 1.2456 \quad u_{i-1} - 0.2976 \quad u_{i-2} - 0.1954 \quad u_{i-3} + \varepsilon_i(0, \quad 0.5132^2)$$

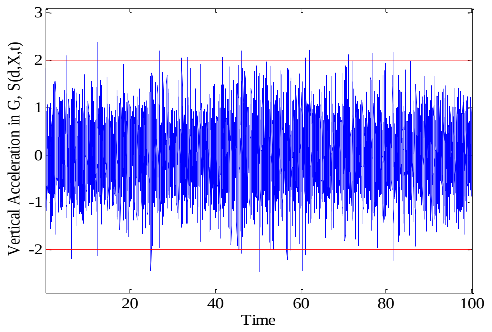
Statistical tests were performed to verify the model

Observations

Accel. (G)



Terrain

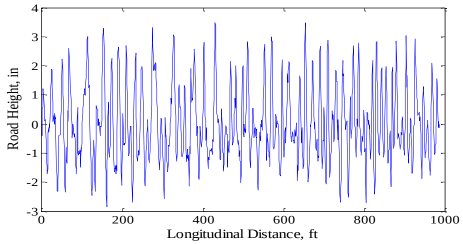


Stationary input random process + **Linear system** → **Stationary output random process**

Constant (time-independent) failure rate

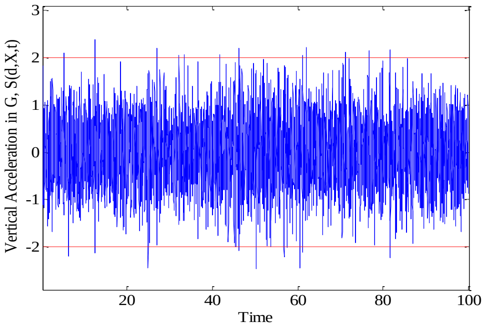
Observations

Random Variables

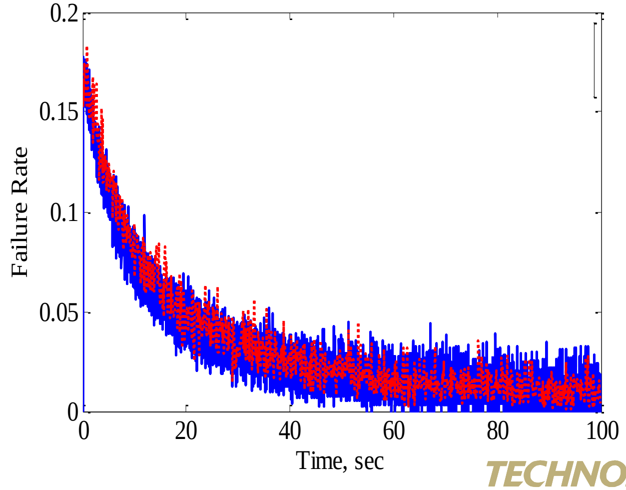


Terrain

Accel. (G)



Time-dependent failure rate



Problem Description/Approach

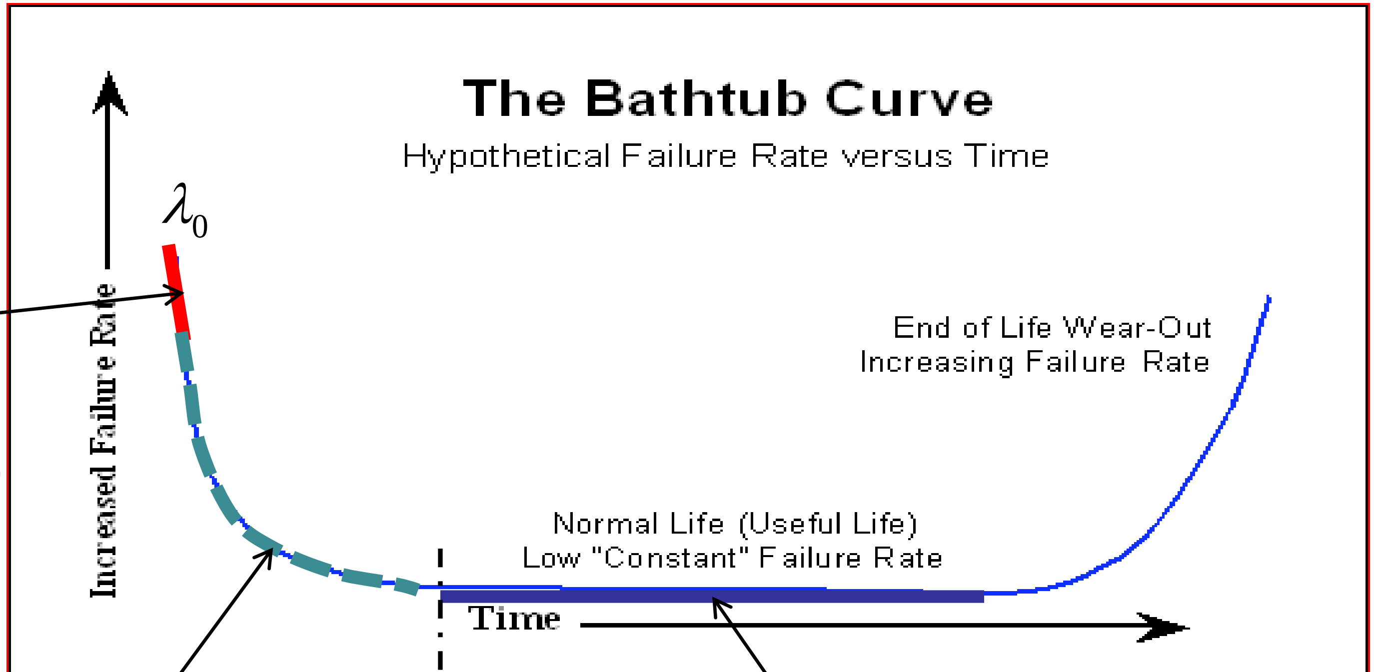
Vehicle speed : 20 mph; Mission distance : 100 miles

Simulation can be practically performed for a short-duration time

A novel MC-based method to calculate failure rate based on :

- **Short-duration data and an exponential extrapolation using MCS or Importance Sampling or Subset Simulation (Infant Mortality)**
- **Poisson's assumption (Useful Life)**

Efficient MC Simulation Approach



MCS

$$b = -\frac{1}{\lambda_0}\left(\frac{d\hat{\lambda}}{dt}\right)_{t=0}$$

t_{int}

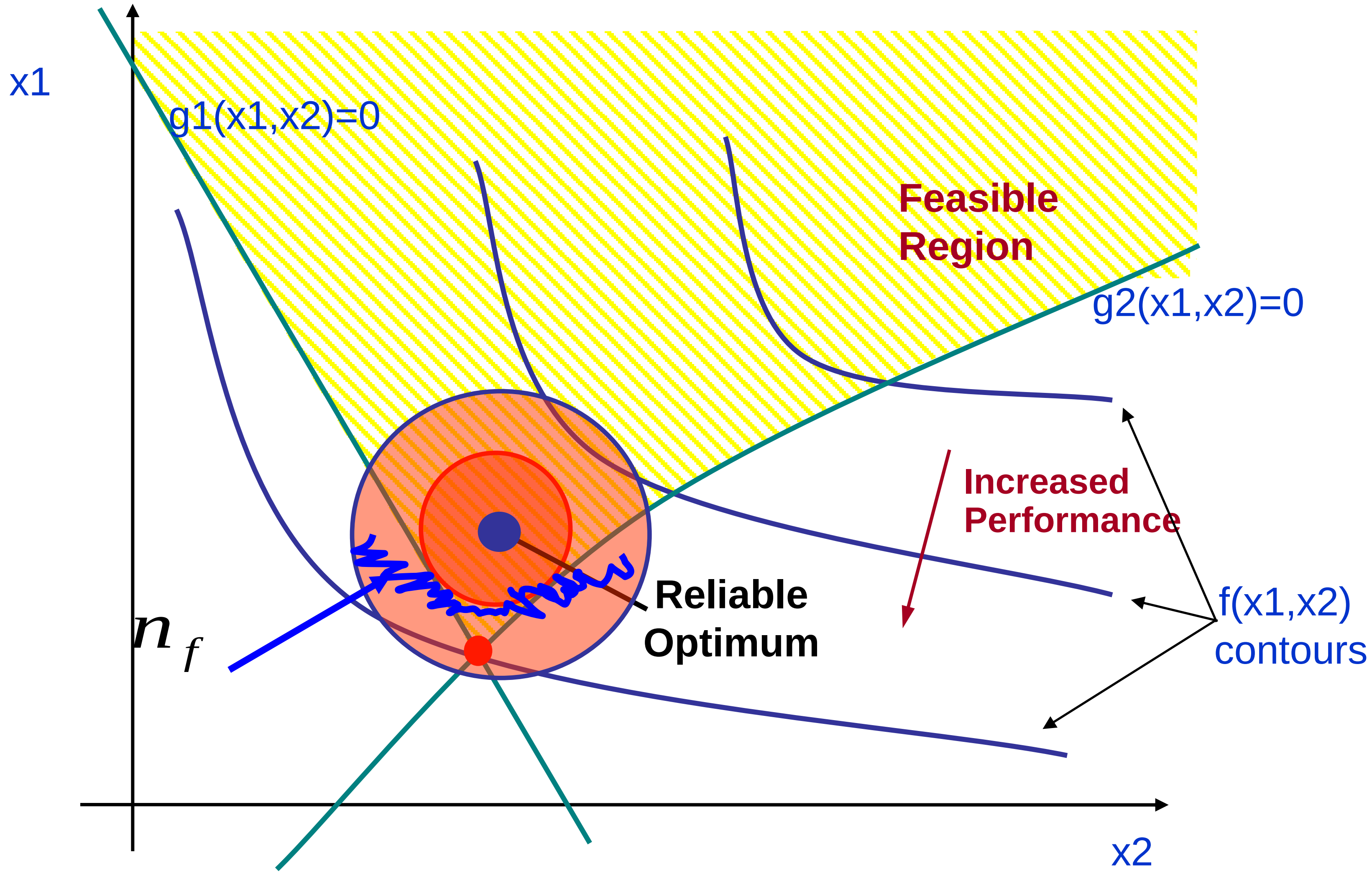
Poisson's Assumption

Exponential Extrapolation

$$\boxed{\hat{\lambda}(t) \approx \lambda_0 e^{-bt}}$$

$$F_T^c(t) = \begin{cases} 1 - e^{-\int_0^t \hat{\lambda}(t)dt} & , t \in [0, t_{\text{int}}] \\ 1 - (1 - F_T^c(t_{\text{int}}))e^{-\nu_m (t - t_{\text{int}})} & , t \in [t_{\text{int}}, t_f] \end{cases}$$

Principle of Importance Sampling: Random Variable Case



Importance Sampling for Random Process

$$\lambda(t_i) = \lim_{\Delta t \to 0} \frac{\sum_{n=1}^{N_f(t_i)} \omega(\mathbf{x}, t_i)}{\Delta t \cdot N_S(t_{i-1})}$$

where:

$\omega(\mathbf{x}, t_i) = \dfrac{f_{\mathbf{X}}(\mathbf{x}; t_i)}{f_{\mathbf{X}^S}(\mathbf{x}; t_i)}$: Likelihood ratio at t_i

$N_S(t_{i-1})$: Safe sample points at t_{i-1}

$N_f(t_i)$: Number of failures in $\Delta t = t_i - t_{i-1}$

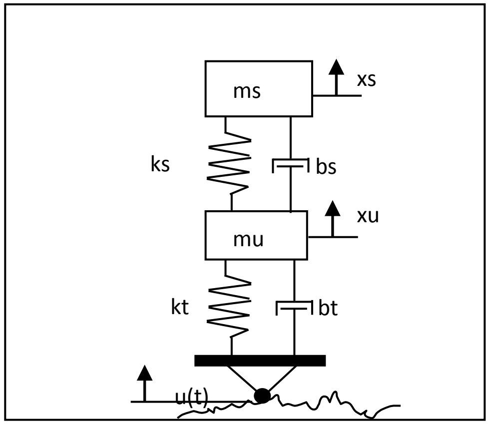
Quarter-Car Model on Stochastic Terrain

Constant design parameters:

ms =1000 kg

mu =100 kg

Vehicle speed = 20 mph



Random Input variables

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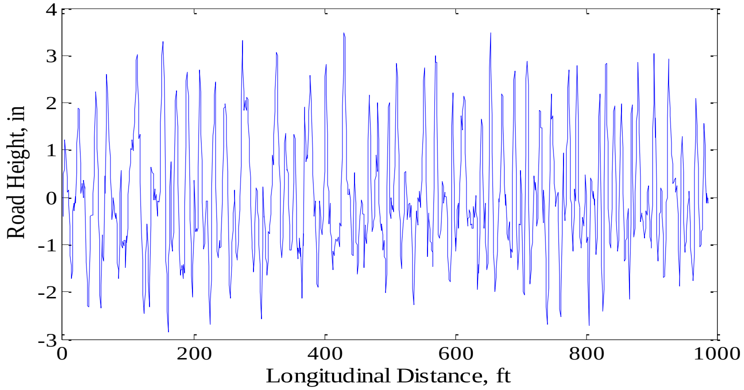
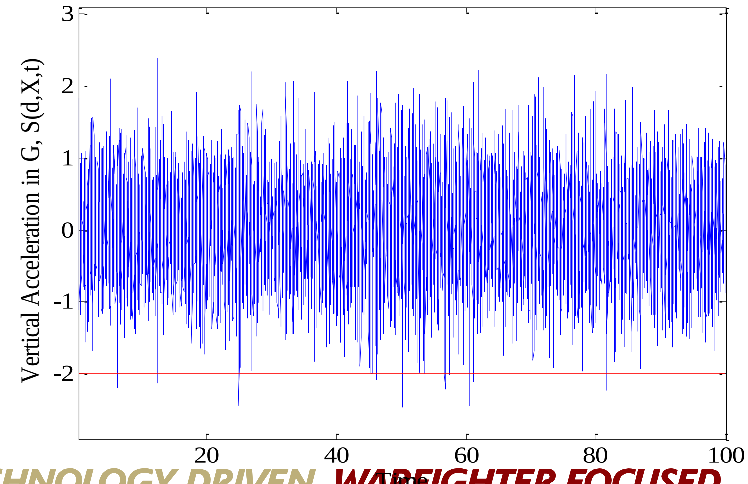
Random Output Process
(Vertical Acceleration, G')

Random Input Process: Experimental Stochastic Terrain from Yuma Proving Grounds.

Threshold = 2G

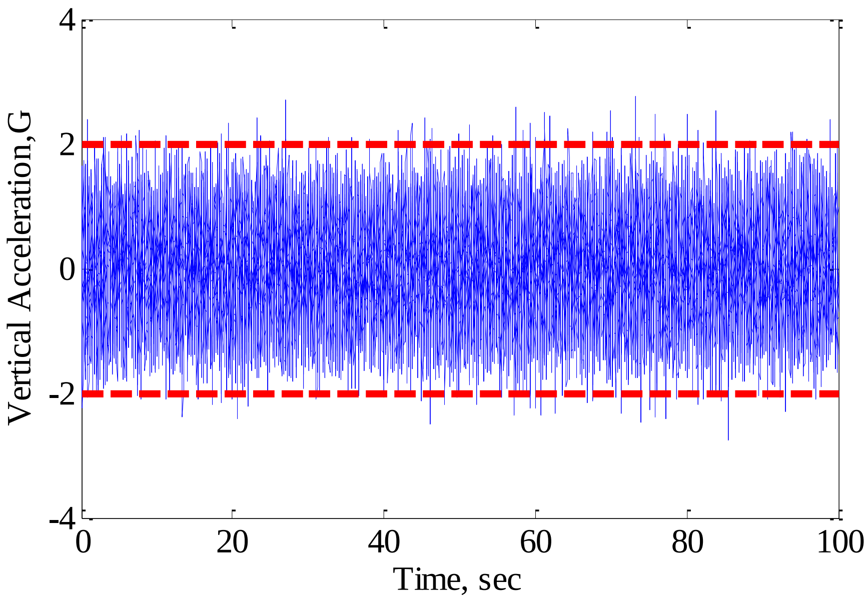




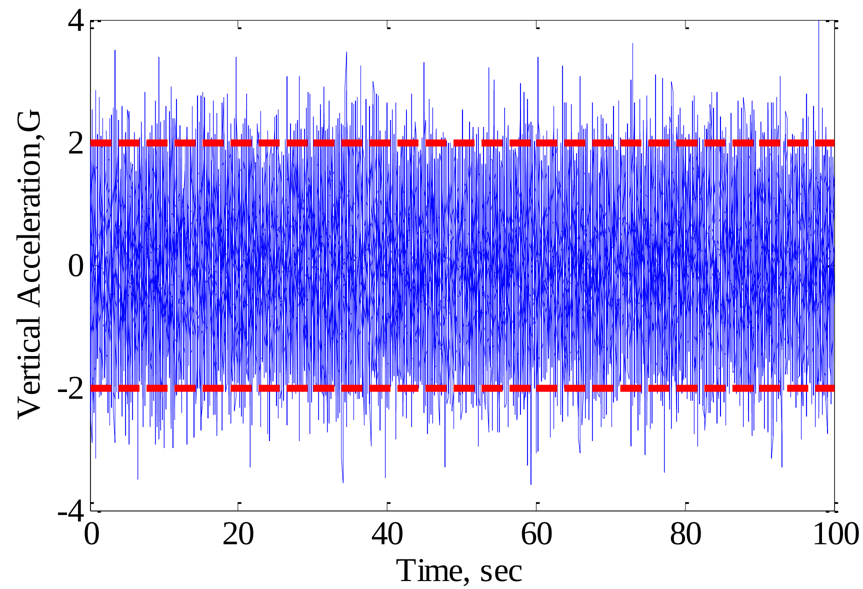
Quarter-Car Example

$$u_i = 1.2456 u_{i-1} - 0.2976 u_{i-2} - 0.1954 u_{i-3} + \varepsilon_i (0, 0.5132^2)$$

Original PDF $\sigma_e = 0.51$



Sampling PDF $\sigma_s = 0.7$

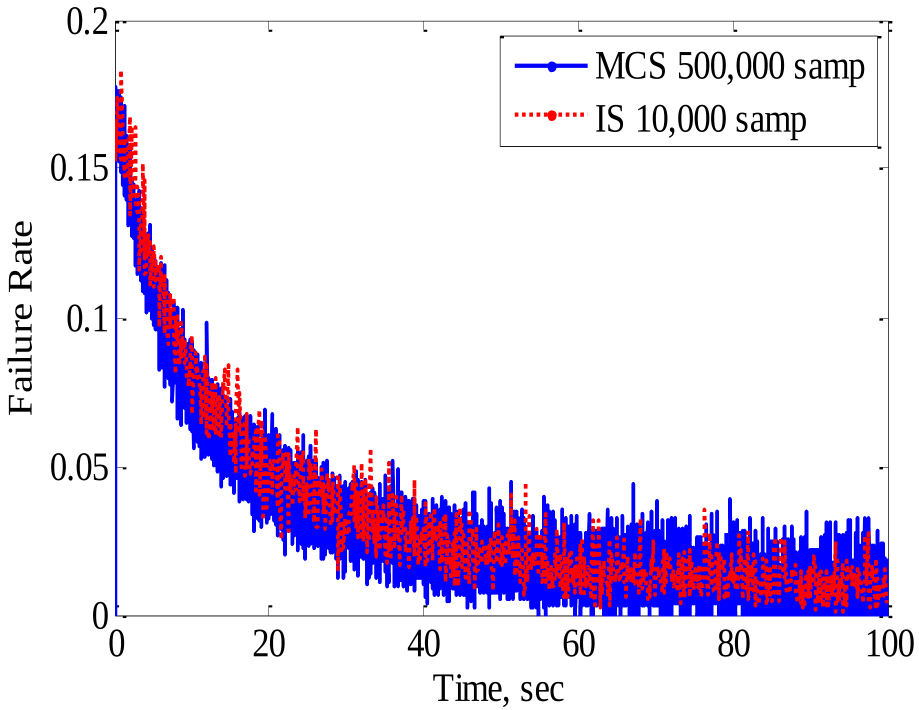


The sampling PDF results in more failures

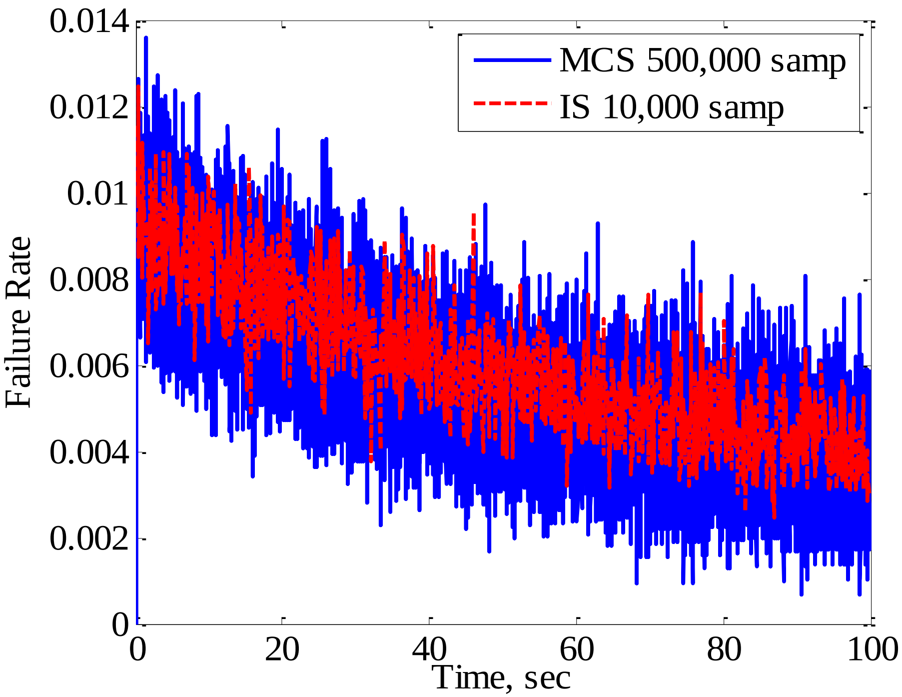
Quarter-Car Example

Non-Stationary Case

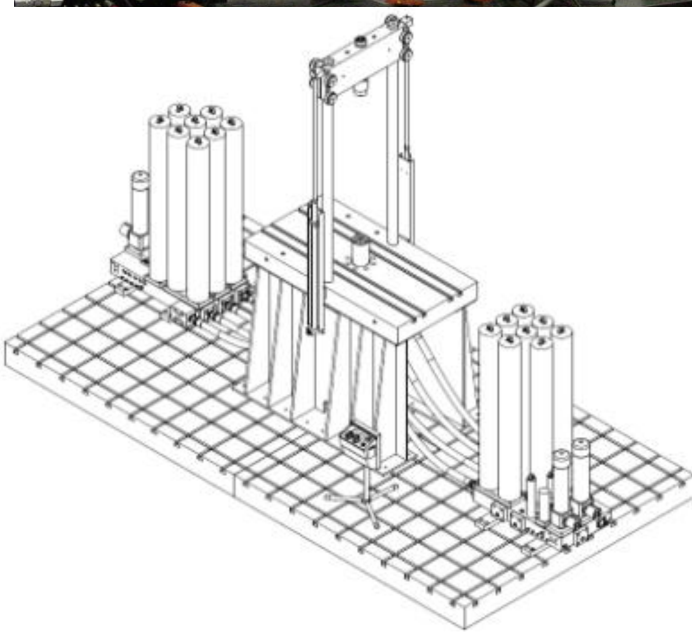
Threshold = 2 g



Threshold = 2.65 g



Accelerated Testing Research



Actuator Capabilities

- Force ration 190 KN
- Dynamic stroke 355 mm
- Velocity 9.1 m/sec
- Force rating of load cell transducer 55 Kip

Analysis Capabilities

- Fatigue Damage Estimate
- Statistical Time History Editing
- Cycle Counting Analysis

How to Get Involved in Research with TARDEC

- SBIR- Small Business Innovative Research
- Automotive Research Center (ARC)- Alliance between US Army and academia (University of Michigan- Ann Arbor, Clemson University, Oakland University, Virginia Tech, and others). http://arc.engin.umich.edu/.
- Simulation Based Reliability and Safety (SimBRS)
- Cooperative Research and Development Agreement (CRADA).
- Innovation Grants

Thank You!

Q&A